

The liquefaction susceptibility, resistance, and response of silty and clayey soils

Award Number: 05HQGR0009
Research Period: 12/1/04 - 11/30/05

Jonathan D. Bray, Ph.D., P.E.

University of California, Berkeley
437 Davis Hall, MC-1710
Berkeley, CA 94720-1710
Tel. (510) 642-9843
Fax. (510) 642-7476
bray@ce.berkeley.edu
URL: <http://www.ce.berkeley.edu/~bray/>

Program Element III. Research on Earthquake Physics, Occurrence, and Effects (100%)

Keywords: Liquefaction (65%), Earthquake Effects (20%), Regional Seismic Hazards (15%)

PROJECT OBJECTIVE AND SCOPE

The primary goal of the proposed study is to assess the cyclic response of soils with significant fines (both plastic and non-plastic). The advanced cyclic testing of the low plasticity silty and clayey soils is required to characterize the liquefaction susceptibility of fine-grained soils to evaluate their liquefaction resistance and to gain insight regarding their post-liquefaction response (i.e. volumetric strain and residual strength). Cyclic simple shear testing (with some complementary cyclic triaxial testing for comparison) will be performed on the silty and clayey soils that are on-hand in the U.C. Berkeley geotechnical laboratory. These soils possess a range of soil characteristics that represent many fine-grained soils in the San Francisco Bay area (e.g. Santa Clara Valley), California, and the United States.

INVESTIGATIONS UNDERTAKEN

The investigation over the past year has focused on three main areas. The first was the cataloging and batching of the silty soils on hand. Second was an in-depth look at the mineralogy. The last is the process of developing sample specimens using the reconstituted silts.

I. Categorization and Development of Testing Materials

Over 402 individual samples were returned from Adapazari, Turkey following on site investigation by R. Sancio (Bray et al. 2004b). These samples came from SPT and thin-wall samples retrieved from seven sites. Each sample was cataloged according to the following:

- location in Adapazari
- section of the sample

- depth
- plasticity index (PI)
- water content (w_c)
- liquid limit (LL)
- fines content (amount passing 74 μm)
- amount passing 2 μm
- amount passing 5 μm , and
- weight of each sample

Using this information, samples could easily be retrieved for further analysis.

It was decided that the baseline material for the research would have a fines content of 80% and a PI of 10. Once this was established, materials with a fines content between 76 and 84 with a PI between 8 and 13 were mixed together to develop a reasonable uniform batch of material. The dry material is then brought up to the initial bulking water content, about 12% to remain until tested. This water content is sufficient to hold fines in place and decrease segregation through gravitational processes.

Atterberg Limits were performed on two independently taken specimens to determine that the new batched material has a PI of 10 and a LL of 31. Hydrometer testing for fines content is to be completed shortly.

II. Mineralogy

a. X-Ray Diffraction.

To better understand the Adapazari soils, three representative soils were sent to Willamette Geological Service in Philomath, Oregon for X-Ray Diffraction. Each was taken from a different location and at different depths. Information on each soil is given below:

- S1: C10-P3A, Depth: 2.3m, PI = 19, LL = 47, UCSC: ML, Fines Content ~100%
- S2: D4-P2B, Depth: 2.0m, PI = 11, LL = 33, UCSC: CL, Fines Content~80%
- S3: F9-P2A, Depth: 1.8m, PI = 0, LL = 29, UCSC: ML, Fines Content~80%

Upon inspection, the clay mineral assemblage includes smectite (or highly expandable randomly interstratified illite/smectite, 80-90% expandable layers), chlorite (intermediate Fe-Mg composition), illite (muscovite in the coarser fractions), and kaolinite (increasing disorder with decreasing particle size).

Smectite is the dominant component of the finest clay fraction, but illite is the most abundant clay in the coarser clays. The three soils appear to be genetically related, stemming from similar parent materials.

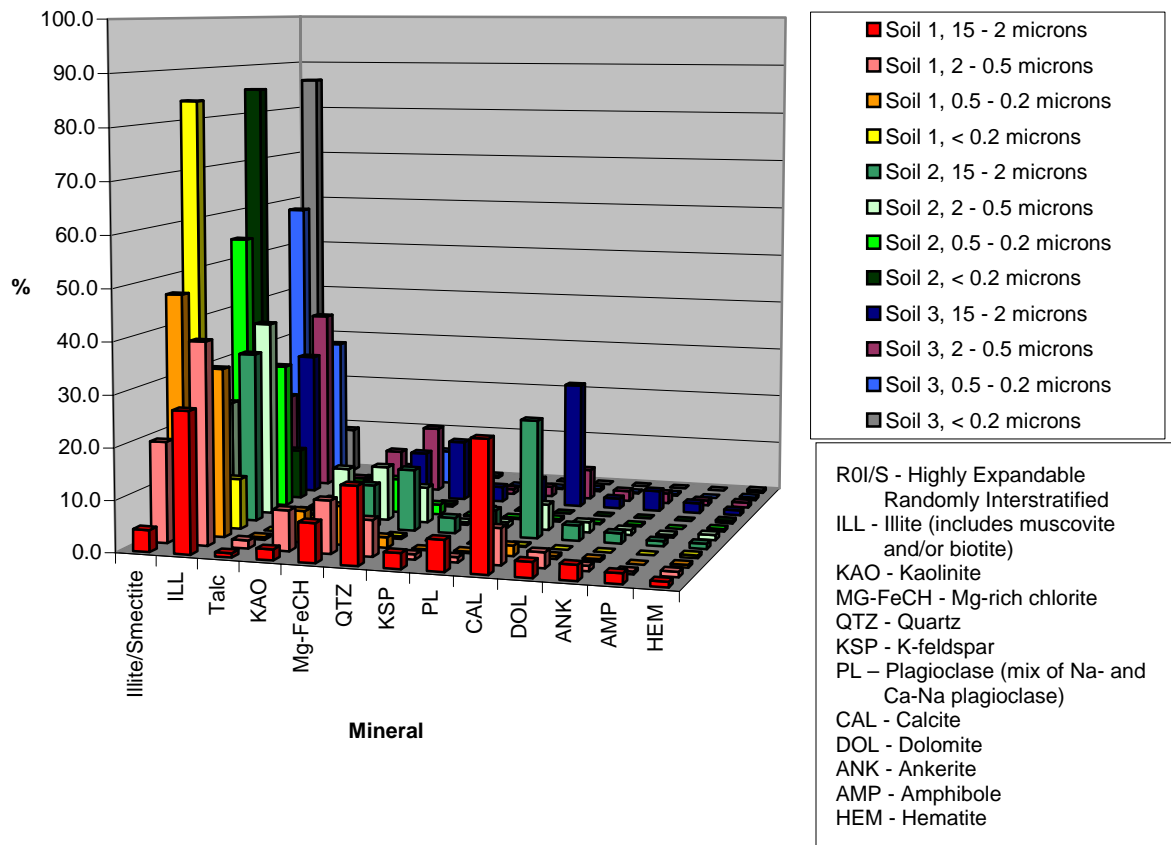


Figure 1. Mineral Interpretation for Three Soils Segregated into Four Sizes

The parent material appears to have moderately calcic plagioclase, hornblende or amphibole, K-feldspar, quartz, calcite, and a mix of dolomite and ferroan dolomite (possibly as ferroan as ankerite). Calcite is a major component of the <15-2- μ m clays and is present in lesser amounts in the <2- and <0.5- μ m fractions. It is a trace component or absent in the <0.2- μ m clays. The calcite component could be pedogenic, although much of the pedogenic carbonate is very micritic and tends to be observed in the finer soil size fractions. The presence of dolomite suggests possible detrital carbonates, although there is the possibility of ankerite in paleosols as a pedogenic phase. In each case, the <0.2- μ m clays are approximately 85% smectite, 10% illite, and 5% other clays (chlorite and kaolinite), with only traces of quartz and calcite.

b. Scan Electron Microscope

Further analysis of the baseline material was performed by the Scan Electron Microscope (SEM) on the following soil.

- Soil Sampled: A6-P5A, Depth: 3.9 m, PI = 9, LL = 31, UCSC: CL, Fines Content ~80%

This soil was first segregated into five categories: 1- μ m, 2- μ m, 5- μ m, 20- μ m, and 20+ μ m.

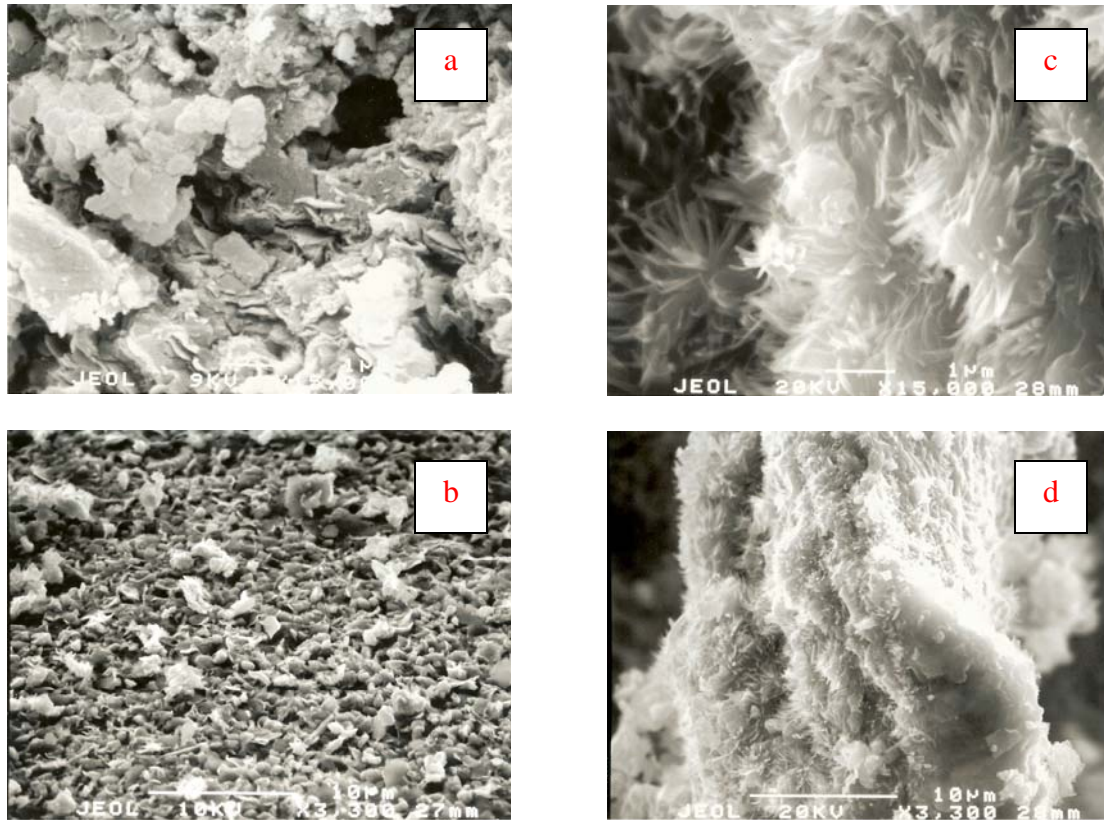


Figure 2. Representative photos of 1(minus) micron: a) platy materials at 15,000x zoom, b) material surface at 3,300x zoom, c) illite at 15,000x zoom, and d) illite shown at 3,300x zoom.

The photos presented in Figures 2 and 3 from the Scan Electron Microscope show the range of minerals within the silt. These types of observations paired with the results from the X-Ray Diffraction provide a reasonable description of the material components. In the future, these mineralogies may be telltale signs of liquefaction susceptibility for silts.

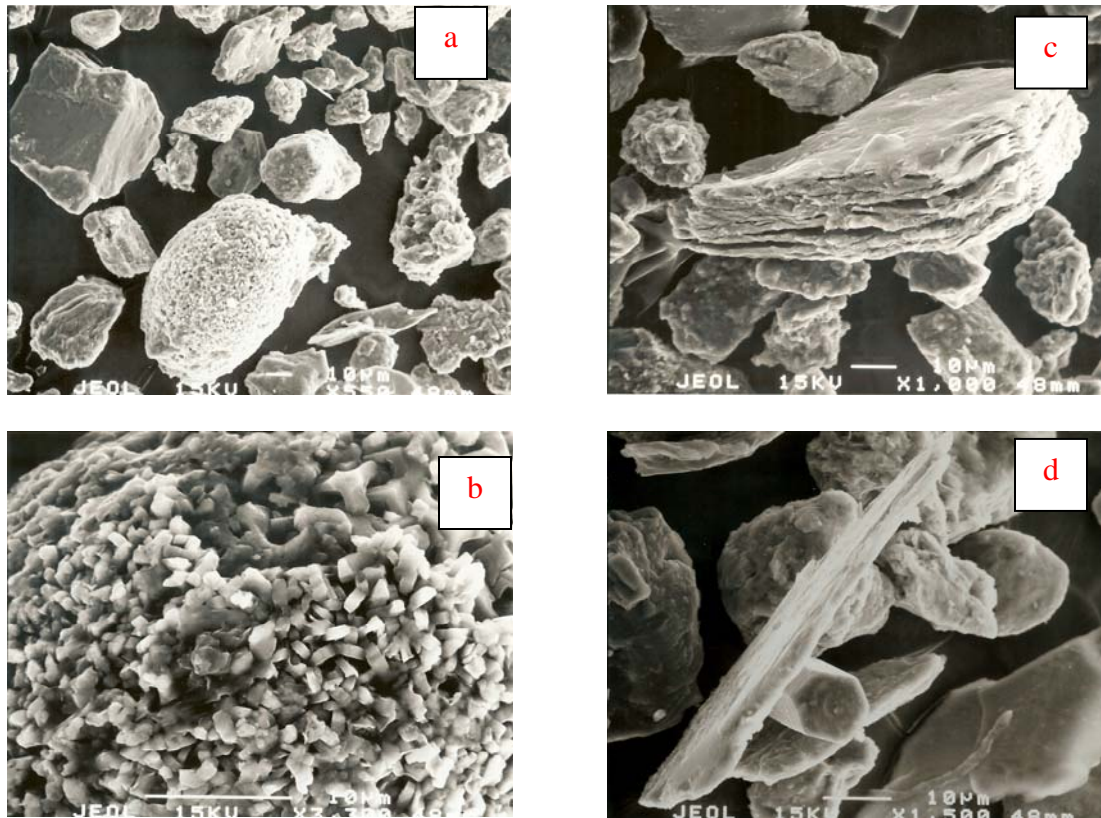


Figure 3. Representative photos at 20(plus) microns: a) two interesting particles, one “brain-like,” and the other cubical at 550x zoom, b) close-up of “brain-like” element at 3,300x zoom, c) platy material at 1,000x zoom, and d) hexagonal element at 1,500x zoom

III. Specimen Reconstitution

Specimen preparation of reconstituted silt specimens was one of the major challenges to this program of research. However, after extensive testing and experimentation, a reliable specimen reconstitution method has been developed.

To date, most specimen reconstitution has been performed on sands and silty sands. Kuerbis and Vaid (1988) has been the primary means for this technique. This method has been proven to produce uniform, non-segregated specimens of sand and silty sand soils. However, because of reduced hydraulic conductivity of the Adapazari silts, this technique was found after an extensive trial use to not be appropriate for silts. Moist tamping was also ruled out, as it did not represent a natural depositional method.

Zdravkovic (1996) developed a method of reconstituting silts for use in a cyclic torsional shear device. The premise of this method was adopted and modified for the development of specimens

for the cyclic triaxial device. This new method is not described in its entirety, but the highlights are given below.

The material begins at a state of 12% water content as described previously. Water is added to bring the material up to a water content of approximately 45%. At this water content, the material has become a slurry for optimum workability. The vacuum triaxial mold is assembled and the material placed inside the mold. Approximately 4 in. Hg, or 13.5 kPa, is applied through a vacuum chamber attached to the top and bottom of the specimen. An additional 6 kg, or 10 kPa, is applied vertically to the top of the specimen.



Figure 4. Specimen inside vacuum mold consolidating from a slurry. Specimen is also attached to vacuum chamber delivering 0.13 atm vacuum at top and bottom with 6 kg load vertically applied.

Using this combination and letting the specimen consolidate for one or two days yields a specimen able to stand erect from what was once a slurry. The specimen may now be transferred to the cyclic triaxial device to be consolidated to either a K_0 or isotropic state for testing. The low pressures exerted by the vacuum chamber and vertical load can easily be erased during consolidation.



Figure 5. Specimen once vacuum mold has been removed, while still under confining pressure from vacuum chamber.

This silt specimen preparation method is continuing to be tested to establish its repeatability and uniformity. Hydrometer tests are being performed to verify the uniformity of the specimen at three different locations within the specimen and to compare to a control specimen. Water contents from six locations will also be sampled.

After the results from this evaluation of the silt specimen preparation method is completed and its viability and robustness is assured, it is anticipated that a full write-up with results will ensue with the appropriate journal articles and ASTM submission for the reconstitution of silts.

RESULTS

The project baseline is considered to be 80% fines content with a PI equal to 10. A specimen prepared as stated above was tested using the UC Berkeley cyclic triaxial device with the following results as shown in Figure 6. The specimen reached 3% single amplitude strain on the 10th cycle ($N_f = 10$).

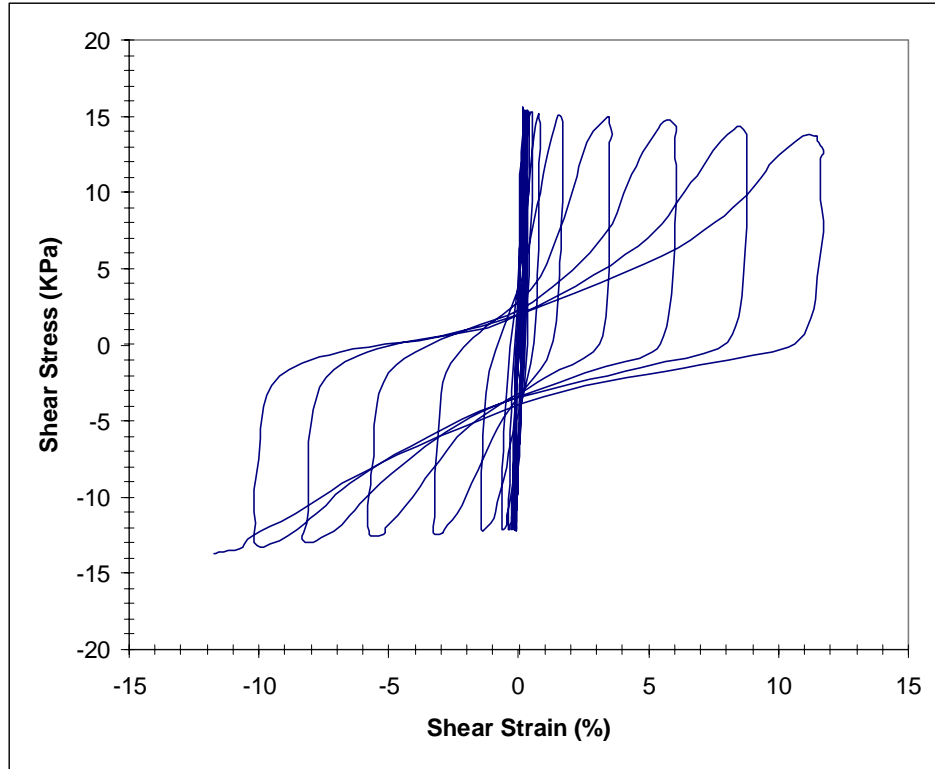


Figure 6. Recorded results for baseline silt, PI=10, Fines Content~80%, $\sigma'_m=60$ kPa, wc/LL=1.0, tested at CSR=0.2.

Previous research by Bray et al. (2004a) on field samples suggested that the number of cycles required to reach 3% axial strain (N_l) increases slightly from $N_l = 11$ at PI = 0, to $N_l = 13$ at PI = 7, to $N_l = 15$ at PI = 11, and then N_l increases abruptly to 139 (an order of magnitude) when the PI of the soil is 18. However, these soils were at different void ratios and water content to liquid limit ratios, and a higher CSR was applied for these particular tests, so additional testing is required to identify trends in the cyclic resistance of silty soils with increasing soil plasticity.

This research program is designed to use uniform reconstituted specimens that may be tested in an organized manner to minimize the significant inherent variability of natural soils, so that specific factors can be isolated and evaluated (Figure 7). The baseline silt mixture will be tested at different void ratios, CSRs, water content to liquid limit ratios, and effective confining pressures. Comparison of different silts such as a fines content of 100% and PI of 20, or a fines content of 50% and a PI of 7, tested in the same manner will bring conclusive evidence as to the factors which primarily affect the cyclic resistance of silty soils.

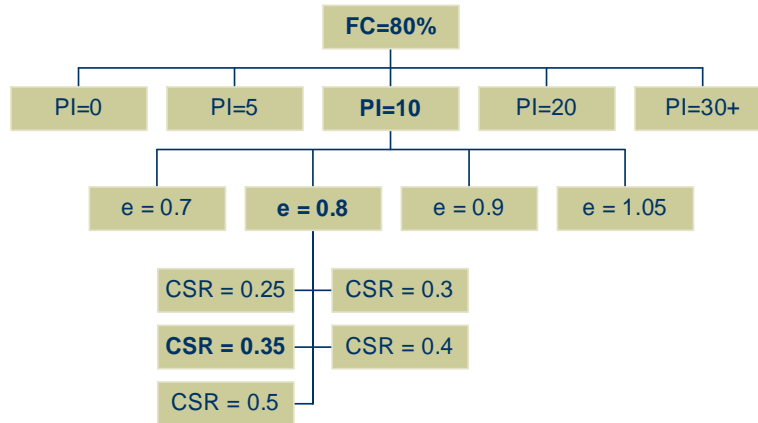


Figure 7. Sample testing matrix for silty and clayey soils. The baseline of 80% fines content is shown. Fines contents of 50% and 100% will also be tested in a similar fashion.

Cyclic triaxial testing is only the first step in the lab testing process. A majority of the testing will be accomplished on the cyclic shear device, which more closely resembles the actual earthquake processes. Lastly some cyclic torsional shear testing will be performed using a recently developed bench-top testing device developed by Dr. Riemer as part of the downhole torsional shear equipment project sponsored by Caltrans.

NON-TECHNICAL SUMMARY

An enhanced understanding of the response of fine-grained soils during earthquakes is required so that we can understand the seismic response of these commonly occurring soils as well as we understand that of clean sand. A significant amount of advanced testing is required to develop a database of experimental results upon which to characterize silty soils and to build robust soil constitutive models for advanced dynamic analysis. Much research has been performed on clean sands and soft clays in geotechnical engineering. It is now time to investigate silts comprehensively, and the proposed research supports this important effort.

REPORTS PUBLISHED

None at this time.

DATA AVAILABILITY

Jennifer L. Donahue
 Phone. (415) 637-7454
 E-mail: jennifer_donahue@earthlink.net
 Format: MS Excel and MS Word

REFERENCES

- Bray, J.D., Sancio, R.B., Riemer, M.F. and Durgunoglu, T. (2004a). "Liquefaction Susceptibility of Fine-Grained Soils," *Proc. 11th Inter. Conf. On Soil Dynamics and Earthquake Engineering and 3rd Inter. Conf. On Earthquake Geotechnical Engineering*, Doolin et al., Eds., Berkeley, V.1, pp. 655-662.
- Bray, J. D., Sancio, R.B., Durgunoglu, H.T., Onalp, A., Youd, T.L., Stewart, J.B., Seed, R.B., Cetin, O.K., Bol, E., Baturay, M.B., Christensen, C. and Karadayila, T. (2004b). "Subsurface Characterization at Ground Failure Sites in Adapazari, Turkey," *J. Geotech. Engrg.*, ASCE, Vol. 130, No. 7, July.
- Kuerbis R, and Vaid, Y.P. (1988) "Sand Sample Preparation – The Slurry Deposition Method", *Soils and Foundations*, Vol. 28, No. 4, pp. 107-118
- Zdravkovic, L (1998) "The stress-strain-strength anisotropy of a granular medium under general stress conditions", Thesis, University of London, Imperial College of Science, Technology and Medicine.